Evaluating Diatomaceous Earth, Silica-Aerogel Dusts, and Malathion To Protect Stored Wheat from Insects

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UNITED STATES DEPARTMENT OF AGRICULTURE

PREFACE

This report presents results obtained in 3 years of observations of 90,000 bushels of wheat treated with low mammalian toxicity insecticides and stored under field conditions in Kansas.

This publication reports research involving pesticides. It does not contain recommendations for their use, nor does it imply that the uses discussed here have been registered. All uses of pesticides must be registered by appropriate State or Federal agencies, or both, before they can be recommended.

Diatomaceous earth may be applied to stored grain for insect control according to label instructions approved by EPA. Agricultural Marketing Service (AMS) provides instructions to licensed grain inspectors for grading grain containing diatomaceous earth (under GR Instruction 918-4 Aux. 1, May 9, 1963). An applicant who has grain that contains or appears to contain diatomaceous earth and who wishes to have the grain graded may file a written application with the grain inspector. If diatomaceous earth is then found, the grain will not be downgraded on the basis of the presence of an unknown or foreign substance.

Malathion has an established tolerance of 8 parts per million when applied to stored wheat for insect control and may be used according to label instructions.

CAUTION: Pesticides can be injurious to humans, domestic animals, beneficial insects, desirable plants, and fish or other wildlife—if they are not handled or applied properly. Use all pesticides selectively and carefully. Follow recommended practices for the disposal of surplus pesticides and pesticide containers.

PROTECT

Use Pesticides Safely

FOLLOW THE LABEL

U.S. DEPARTMENT OF AGRICULTURE

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ACKNOWLEDGMENTS

The entomological phases of the study were carried out at the U.S. Grain Marketing Research Center (formerly the Midwest Grain Insects Investigations Laboratory), Manhattan, Kansas, and at the McPherson County Agricultural Stabilization and Conservation Service (ASCS) binsite in McPherson, Kansas. Malathion residue analyses were made by the Chemical Unit, Stored-Product Insects Research and Development Laboratory, Savannah, Ga. Both the Manhattan and the Savannah Laboratories are field stations of the Agricultural Research Service, U.S. Department of Agriculture.

Agricultural Research Service personnel who contributed substantially to the project include Warren E. Blodgett, Ralph L. Ernst, Leon H. Hendricks, and Edwin B. Dicke, all of whom assisted in the field and laboratory entomological phases of the work.

Acknowledgment is extended to Raymond Whitney and Gordon W. Barnes of the ASCS at Manhattan, Kans., and to their supervisors who made it possible for this work to be conducted in Commodity Credit Corporation (CCC) grain. Special thanks is expressed to Arnold L. Serviss, Austin Elwood, Lewis Nelson, and Walter Zerger, of the ASCS office in McPherson County.

CONTENTS

Insects mentioned in this report

Common name	*Scientific name*
Angoumois grain moth	*Sitotroga cerealella* (Olivier)
Bean weevil	*Acanthoscelides obtectus* (Say)
Cadelle	*Tenebroides mauritanicus* (Linnaeus)
Confused flour beetle	*Tribolium confusum* Jacquelin duVal
Cowpea weevil	*Callosobruchus maculatus* (Fabricius)
Dermestid	*Trogoderma inclusum* LeConte
Flat grain beetle	*Cryptolestes pusillus* (Schönherr)
Flour beetles	*Tribolium* spp.
Granary weevil	*Sitophilus granarius* (Linnaeus)
Indian meal moth	*Plodia interpunctella* (Hübner)
Lesser grain borer	*Rhyzopertha dominica* (Fabricius)
Longheaded flour beetle	*Latheticus oryzae* Waterhouse
Mediterranean flour moth	*Anagasta kuehniella* (Zeller)
Rice weevil	*Sitophilus oryzae* (Linnaeus)
Sawtoothed grain beetle	*Oryzaephilus surinamensis* (Linnaeus)

Evaluating Diatomaceous Earth, Silica-Aerogel Dusts, and Malathion To Protect Stored Wheat from Insects

By Gailen D. White,[1] Wayne L. Berndt,[2] and Joseph L. Wilson[1]

SUMMARY

A field-scale test was conducted over a 3-year period using 90,000 bushels of Hard Red Winter wheat. Two diatomaceous earth materials, Perma-Guard and Kenite 2-I, and two silica-aerogel materials, Cab-O-Sil and SG-68, were compared with the standard treatment of malathion. Wheat was stored in 3,250-bushel circular metal bins at the McPherson, Kans. Agricultural Stabilization and Conservation Service (ASCS) binsite. Test materials were mixed with the wheat as it was moved from one bin to another.

The wheat was sampled periodically every month, the first year, then every 3 months the second and third years to determine insecticidal effectiveness, repellency, physical changes of the wheat pertaining to grade, and chemical residues. Samples were supplied to Field Crops and Animal Research Branch for flour quality, milling, and baking tests. The moisture content of the wheat in these tests was uniformly low, and this factor undoubtedly contributed to length of protection afforded.

Malathion-treated wheat remained insect-free for a period of 24 months with an average of 0.35 insect per 1,000 grams of wheat after 3 years of storage; Perma-Guard was next best in performance with an average of 1.8 insects per 1,000-gram wheat sample recorded 3 years after treatment. Kenite 2-I-treated wheat rated third, averaging 43.9 insects per 1,000-gram wheat sample 3 years after treatment. The silica aerogels, SG-68 and Cab-O-Sil, gave protection early in the test, but after 3 years, the bins harbored more insects than the untreated check wheat which then contained an average of 100 insects per 1,000 grams.

Repellency tests showed diatomaceous earth-treated wheat more repellent to insects than the silica-aerogel treatments. The repellency of the inert dusts, in general, was not reduced as the storage period increased. The malathion-treated wheat was originally slightly repellent, but gradually became less repellent to test insects as time progressed.

Bioassay tests, which were conducted under laboratory conditions, indicated the diatomaceous earth treatments produced nearly 100 percent mortality of the rice weevil throughout the test period. Malathion was equally (nearly 100 percent) effective against the rice weevil for 2 years, but mortality counts decreased the third year. The silica-aerogel wheat treatments closely followed the malathion pattern in causing adult rice weevil mortality.

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the inert dust materials were applied to the wheat and again when the dust-treated wheats were removed from the bins at the termination of the test. Dust-treated wheat increased machinery stress and maintenance problems and slowed grain movement.

BACKGROUND

Emphasis is being placed on reducing environmental contamination; one aspect is minimizing the use of chemical pesticides. Increased restriction on the use of pesticides, growing insect resistance, and prolonged storage of large quantities of grain cause problems which must be met, and yet the public demand for cleaner, uncontaminated food must be satisfied.

Primarily because of their chemical inactivity, lack of mammalian toxicity, and lasting persistance, inert dusts were chosen for three simultaneous large-scale grain treatment test series for stored grain insect control in corn in Illinois and Georgia, and wheat in Kansas. This report is on the treatment of wheat in Kansas.

Two types of inert dusts were employed: Diatomaceous earth and silica aerogel. The dust treatments were compared with a standard malathion wheat treatment.

Diatomaceous earth occurs in large sedimentary deposits in many parts of the world. It is formed by countless numbers of skeletal diatoms. Diatoms, in general, are unicellular or colonial algae constituting a class, Bacillariophyceae. They occur abundantly in salt and fresh water and in soil. They possess a silicified cell wall that persists as a skeleton after death and forms diatomite, almost pure silica. This chalklike appearing material is removed from deposits and ground or pulverized to varying degrees of fineness and marketed for many industrial uses.

Silica aerogel, made from silica gel, is colloidal silica in the form of a fine lightweight powder.

Among the first materials man used as covers to prevent insects from destroying his stores were ashes, sand, and dust. For many centuries, the practice of mixing wood and aloe ashes with grain has been used in South Africa and India to control insect infestations. Some American Indians covered their corn in mounds of sand. A mixture of calcium phosphate and sulfur (Katelsousse) has been used for insect control in the Middle East, a hydrated ferrous phosphate (Vivianite) in Russia, and finely ground quartz (Naaki) in Germany.

The insecticidal action of inert dusts has been studied by researchers throughout the years (*1, 3, 5, 8, 10*).[3] Wigglesworth (*20*), in an early report, concluded that cuticular abrasion was the prime factor contributing to the evaporation of insect body water and death. Ebeling (*7*) showed that powders absorb cuticular wax at varying speeds and such sorption permits water loss and knockdown. Cotton and Frankenfield (*4*) reported that silica aerogel was effective against stored-grain pests in wheat. McGaughey (*17*), found that the diatomaceous earth, Perma-Guard, produced 100-percent mortality in rice weevils and confused flour beetles exposed for 21 days in rough rice treated with dosages of 1.75 and 3.5 g/kg (7 pounds of dust per ton is equivalent to 3.5 g/kg). Treated milled and brown rice required an increased dosage and an exposure period of more than 56 days to effect 100-percent mortality of confused flour beetles. McGaughey speculated that the lower mortalities in the milled and brown rice appeared to result from saturation of the diatomaceous earth by oils from the rice.

A comprehensive review of investigations of the use of inert dusts for the protection of stored grain, made by the Stored-Product Insects Research Laboratory under the Agricultural Research Service, and the Agricultural Marketing Service, and the former Bureau of Entomology and Plant Quarantine, are reported in Agricultural Research Service publication ARS 51-8 (*19*).

Carlson (2) 1961-62 found in laboratory tests, that dosages of 5 and 7 pounds of diatomaceous earth per ton of wheat resulted in complete kills of flat-grain beetles and rice weevils, respectively, after 2 weeks exposure. Carlson in his publication with Ball presents also a most comprehensive literature review on inert dusts as insecticidal materials.

Strong and Sbur (*18*), reported that 4 pounds of diatomaceous earth per ton of wheat prevented

[3] Italicized numbers in parentheses refer to Literature Cited, page 18.

test insect infestations for 6 months, 6 pounds for 9 months, and 8 pounds for 12 months—at which time the test was terminated.

La Hue (*12*) in 1966 reported that damaging infestations of mixed populations of insects became established during a 12-month test period in small bins of corn which had been treated with diatomaceous earth.

La Hue (*15*) in 1967 evaluated in a small-bin test the four inert dusts used in the study reported here as wheat protectants. He found that diatomaceous earth applied to wheat at dosages from 120 to 300 pounds per 1,000 bushels was superior to the standard application of 1 pint of premium grade 57-percent malathion emulsifiable concentrate per 1,000 bushels of wheat in protecting the grain from insect infestation. He also found that silica aerogels, SG-68 and Cab-O-Sil, applied to wheat in small bins at the rate of 15, 30, and 45 pounds per 1,000 bushels gave generally unsatisfactory protection.

Diatomaceous earth and malathion was evaluated by La Hue (*13*) as protectants against insects in sorghum grain in a 12-month study in small bins. Insect infestations were not adequately controlled, and damaging populations became established in all bins.

Silica aerogel, diatomaceous earth, malathion, and diazinon were compared as wheat protectants against the lesser grain borer by La Hue (*14*) in 1970. Silica aerogel (Cab-O-Sil) at 60 pounds per 1,000 bushels afforded nearly complete protection from insect damage for 12 months. The 1-pint rate of application of malathion emulsifiiable concentrate and the 210-pound application of Kenite 2-I were only slightly less effective than was the Cab-O-Sil.

Much of the early work conducted by the Stored-Product Insects Research Branch with inert dusts on stored grain for insect control was exploratory and unpublished. It was reviewed in depth before the initiation of the field tests in this report.

The primary objectives of the research reported here were: (1) to determine, under actual field conditions, the relative effectiveness of malathion and two basic types of chemically inert dusts when mixed with wheat for the control of insect infestations over a long period of storage; (2) to determine their effectiveness in preventing subsequent reinfestation of the stored wheat by stored-grain insects; (3) to determine under actual field conditions the practical problems encountered when inert dusts were used to treat grain; and (4) to determine the effect of the treatments on the milling properties of wheat and baking properties of the flour milled from the treated wheat.

MATERIALS AND METHODS

Storage facilities and grain condition

A 3-year field-scale test was conducted at the ASCS binsite at McPherson, Kans., where approximately 90,000 bushels of wheat were stored in metal bins which were 16 feet high and 18 feet in diameter. Each of 30 standard circular 3,250-bushel metal bins of the McPherson ASCS binsite were filled with wheat to the 2,800-bushel level, allowing room for subsequent probing operations.

The wheat was in good condition, containing 11.4 percent moisture or less. There was evidence of insect infestation by various species in the grain from previous years, especially lesser grain borer, cadelle, and Indian meal moth. There was no general infestation in the bins at the time of treatment.

Before treatment, samples of wheat were taken from the bins and bioassayed at the Manhattan

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FIGURE 1.—Airborne dust associated with the diatomaceous earth-treated wheat as the grain was moved from the bins after 3 years of storage.

flow from the bin into the first auger, a third, man-controlled, universal-jointed screw auger was used to move grain. This unit removed the grain from the bottom of the bin with a minimum of hand scooping.

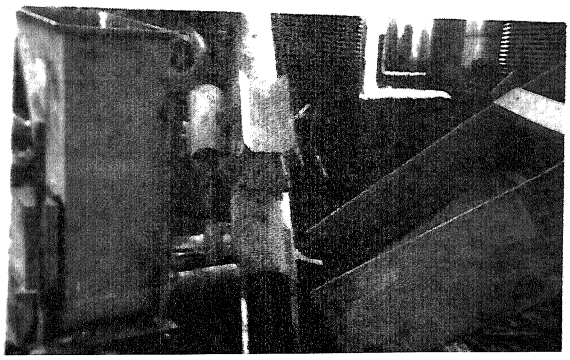
Wheat from the dispatch end of the first auger flowed over 5/64-inch openings of a 10-foot-long metal screen. The screen slanted 45 degrees. This screening operation removed the dust and weed seed, which rendered a more uniform lot of wheat for testing.

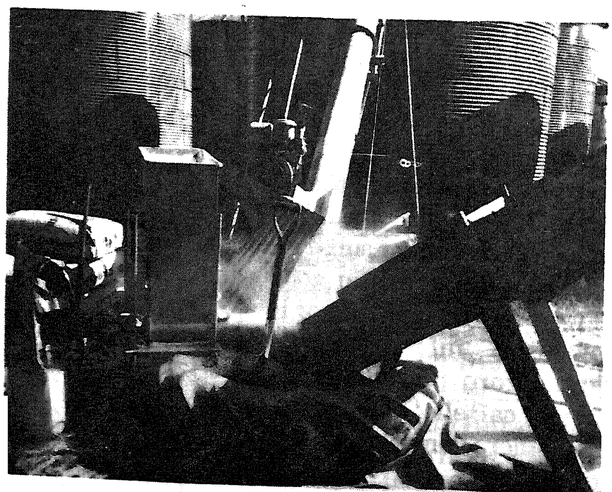
A commercial dust application unit (fig. 2), consisting of a dust hopper, an electric motor-powered screw, and a flow gate by which the amount of dust being applied could be regulated, was used to apply the inert dusts to the grain as it was being picked up by the return 30-foot auger. The dust and grain were mixed by the action of the auger at the point of intake, as the grain traveled through the auger, and again as the grain and inert dust mixture was discharged over a metal distributor cone when it fell into the bins.

Treatment dosage rates

The two diatomaceous earth materials, Perma-Guard and Kenite 2-I, were applied at a rate of 7 pounds per ton of wheat (210 pounds per 1,000 bushels). The two silica aerogel materials, Cab-O-Sil and Dri-Die SG-68, were applied at a rate of 1 pound per ton of wheat (30 pounds per 1,000 bushels). The applied amount of the silica aerogels and diatomaceous earth materials were of about equal volume. There were five replication bins of each treatment.

An emulsifiable concentrate that contained 57-percent premium grade malathion applied at a dosage of 1 pint, mixed with 5 gallons of water, per 1,000 bushels of wheat was used as a comparative treatment. The spray was introduced at a pressure of 20 lb/in^2 through a hole on the upper side of the auger barrel about 1 foot from the pickup end of the 30-foot auger. The malathion spray unit was an electric-driven impeller-type pump equipped with bypass and pressure regula-





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nt (left); dust application unit in operation (right).

tion assembly. As the nozzle was inside the auger, there was no spray drift.

The prevention of spray drift is an important factor in the application of malathion to grain. The action of the auger and the distributor mixed the spray with the wheat. The bin of treated grain was dry to the touch. Five bins of wheat were treated with malathion.

Five bins of untreated wheat were turned in the same manner as the treated wheat. These were retained for comparison as untreated checks.

Materials

Insecticidal materials evaluated were Perma-Guard, Kenite 2-I, Cab-O-Sil M-5, Dri-Die SG-68, and malathion. The malathion formulation was the premium-grade 57-percent malathion emulsifiable concentrate. The two diatomaceous earths, Perma-Guard and Kenite 2-I, were finely divided, naturally occurring minerals. The two silica aerogels, Cab-O-Sil and SG-68, were manufactured silica dusts.

The dusts had properties, as listed (at right) by their manufacturers at the time of purchase.

Perma-Guard:	
Moisture ....percent..	1.5 to 3
Dry density ....lb/ft^3..	20.5 to 24
Retained on 325-mesh screen..percent..	9 to 13
Particle size ....microns..	.1 to 40
Silica (SiO_2), guaranteed .....percent..	minimum 80
Cristobalite ....do..	maximum 1
Surface area* ....cm^2/g..	20,000 to 30,000
Brightness ....photovolt..	60 to 75
Kenite 2-I:	
Moisture ....percent..	8
Dry density ....lb/ft^3..	minimum 14, maximum 15
Retained on 200-mesh screen..percent..	less than 3
Retained on 325-mesh screen ......do..	less than 10
Silica (SiO_2) ....do..	88
Surface area* ....cm^2/g..	30,000
Brightness ....photovolt..	70
pH (aprox.)	7
Cab-O-Sil:	
Free moisture (105° C.) .....percent..	0.2 to 1.5
Apparent bulk density:	
Fluffy grade ....lb/ft^3..	2.5 to 3.5
Bulking value ....gal/lb..	0.057
Particle size range ....microns..	0.015 to 0.020
Silica (SiO_2) ....percent..	99.0 to 99.7
Surface area ....m^2/g..	175 to 200
pH	3.5 to 4.0
Color	white
Refractive index	1.55
Specific gravity	2.1
SG-68:	
Free moisture (105° C.) ......percent..	4.0
Bulk density ....lb/ft^3..	5
Particle size:	
Average ....microns..	3.5
Range ....do..	80% less than 5.5
Silica (SiO_2) ....percent..	99.+
Surface area ....m^2/g..	300
pH (5% dispersion)	7.4
Color	white
Refractive index	1.46
Specific gravity	2.1

*Determined with a Fisher Sub-Sieve Sizer No. 14-311, formerly No. 14-312, calibrator No. 14-313-7, Fisher Scientific Co.

Insect introduction

The absence of natural insect populations in the stored wheat before treatment, necessitated infesting the grain artificially. Insects were added at regular intervals to the wheat as it fell into the hopper from the screen. Every bin in the test was initially infested in early fall with approximately 1,000 of each of the following: rice weevil adults, immature rice weevils residing inside kernels of wheat, lesser grain borer adults, and sawtoothed grain beetle adults.

Observations in the early stages of this test indicated that insect populations failed to develop, even in the untreated check series.

In an effort to hasten population development 8 months later, insects were introduced for the second time in all the bins. About 3,000 lesser grain borers, 3,000 rice weevils, and 200 sawtoothed grain beetles were placed through a ¾-inch galvanized pipe into the top 3 feet of grain in each bin. Placement was about 1 foot from the bin walls where grain was 80° F. The insects were located off the probing quadrants so that the infestation would be less likely to affect samples from subsequent grain probings. Approximately 800 lesser grain borers, 800 rice weevils, and 100 sawtoothed grain beetles were scattered over the surface of the grain (92°) in each bin.

Grain sampling method

Wheat samples were taken from all bins with a standard 5-foot, 11-compartment grain trier, equipped with extensions which made it possible

to draw samples from 15 feet below the grain surface.

The probe sampling pattern was as follows: center-top (5 ft); center-middle (5 ft); center-bottom (5 ft); and at 4 compass points—north, east, south, west (top 5 ft) near the bin walls.

Samples were taken at 1-month intervals after treatment for a period of 1 year. Thereafter, the sampling schedule was changed to every 3 months. The insect count sampling pattern was also changed after the first year to include a surface sample. This was obtained by inserting the grain trier horizontally immediately below the grain surface.

Grain samples were placed in individual plastic-lined grain envelopes and transported to the laboratory for processing.

A portion of the malathion-treated grain samples was sealed in 1-pint glass jars and sent to Savannah, Ga., for residue analysis. From these samples a second portion of each was used in bioassay tests and a third portion was used in repellency tests.

To determine the milling, baking, and biochemical properties of the wheat and flour, each 6 months sufficient grain was taken from 24 of the 30 bins to be sent to the Market Quality Research Laboratory, Beltsville, Md.

At the end of each year, samples were drawn from 15 locations throughout the grain and sent to the Federal Grain Inspectors in Kansas City, Mo., for grain grade determinations. A Boerner Seed Divider was used to divide samples.

Repellency tests

Immediately after treatment and at 3-month intervals, 1,200-gram samples of the wheat, taken from each of the treated bins, were composited and evaluated for repellency to the rice weevil. For comparison, 30,000 grams of untreated wheat were taken from the check bins.

A Berndt-modified[4] Laudani-Swank (*16*) laboratory repellency testing apparatus was employed in these tests.

Twelve ½-pint containers of alternately treated and untreated wheat arranged in rosette fashion, constituted the basis of the testing apparatus. Five hundred adult rice weevils were released in the center of the unit and could enter the containers of their choice. The number of insects found in each container was recorded after 24 hours.

The tests were conducted in a constant temperature-humidity room held at 80° F ± 4° and 60 ± 4 percent relative humidity. The treated and untreated wheat used in the test was preconditioned to these conditions for 24 hours before the test.

The formula used in calculating percent repellency was as follows:

TU = Total insects recovered from untreated grain.
TT = Total insects recovered from treated grain.
TNR = Total insects recovered from test.

$$\frac{TU}{TNR} \times 100 - 50 \times 2 = \text{percent repellency}$$

Example:

$$\frac{325}{440} \times 100 - 50 \times 2 = 47.72 \text{ percent repellency}$$

Positive figures express percent repellency and negative figures express percent attractancy.

Bioassay tests

Wheat samples, taken from the bins every 3 months, were bioassayed in the laboratory at 80° ± 4° F and 60 ± 4 percent relative humidity. The effect of the grain treatments on the mortality of adult test insects and progeny was determined over 3 years.

Two 250-gram portions of wheat from each bin were placed in screened pint glass jars. Fifty adult rice weevils were added to one jar and 50 adult lesser grain borers to the other.

After 21 days of exposure, the 50 adult rice weevils and lesser grain borers were removed from the wheat, and mortality counts were made. The adults were then discarded.

After 63 days of exposure, live and dead progeny counts were recorded from examination of the jars of wheat which contained the emerged offspring of the 50 adult test insects.

Malathion residue analysis

A portion of the wheat probed from the five malathion-treated bins was composited by bin, divided, and sealed in 1-pint glass jars for residue

[4] BERNDT, WAYNE L. SYNERGISM IN THE REPELLENT ACTION OF COMBINATIONS OF PIPERONYL BUTOXIDE AND ALLETHRIN. 1963. (Ph.D. thesis.) Copy on file at the Kansas State University, Manhattan, Kans.

analysis. Samples were taken before treatment, 1 month after treatment, and at 3-month intervals thereafter. These were sent to the Stored-Product Insects Research and Development Laboratory, Savannah, Ga., for malathion residue analysis.

During the second year, the lower limit sensitivity of the malathion analytical method was improved from 0.5 p/m to 0.2 p/m.

Commercial grade

Initially, a composite 15-probe sample of wheat was taken from each bin, both before and after treatment. The composite samples were reduced to 2,000 grams each by using a Boerner Seed Divider and sent for grading. Samples were submitted to the Field Office, Grain Division, AMS, U.S. Department of Agriculture, Kansas City, Mo., for official grain grade determinations (*6*) by Agriculture Commodity graders. This procedure was followed once every 12 months. Commercial grade factors primarily responsible for the original grade and subsequent grade changes are shown in table 9 (Results section).

The wheat treated with aerogels, SG-68 and Cab-O-Sil, were graded, for this test, as though an "unknown foreign substance" were not present. This was done to evaluate other factors affecting the grade. Silica-aerogel treatment of wheat would have normally resulted in a grade of "U.S. Sample Grade."

The wheat grading standards were revised during the test. The before- and after-treatment samples were graded under the old standard, and the 1-, 2-, and 3-year samples were graded under the revised standards. This change did not appreciably affect the results reported herein.

Wheat test weight

Test weights were determined on composited field samples as previously described by the AMS, Grain Division as part of the official grade.

Moisture content of wheat

The percent moisture was determined in the laboratory using a Motomco Moisture meter.

A few simple laboratory tests were conducted where the moisture content of wheat was determined before and after inert dusts were added, and it became apparent that the Motomco unit was not accurately reflecting the moisture content of the treated wheat. This development was again attributed to dust affecting the normal nestling qualities of the grain. Since then, Johnson and Kozak (*11*) conducted tests which showed that the moisture content of wheat, determined by the official oven method was not significantly changed by treatment with diatomaceous earth. They also found that the decreased moisture reading reflected by the Motomco Moisture meter can be compensated for by adding 7.5 grams more of Hard Red Spring, Hard Red Winter, or Soft Red Winter, or 5.5 grams of White wheat, to the usual sample amount of 250 grams.

Milling and baking tests

The effects of the inert dust treatments on the chemical, baking, and physical dough properties were determined by C. C. Fifield, research chemist, Agricultural Research Service, Beltsville, Md. First-year findings were reported in a joint report (*19*). The results of second- and third-year observations were published in 1970 (*9*).

RESULTS

Insect control treatment evaluation

Monthly observations of grain samples the first year failed to reveal insect populations in the 3,250-bushel bins sufficient to evaluate the effectiveness of treatments. Insects were, however, found in the untreated wheat after 12 months, and slowly increased to an average of 39.9 insects per 1,000 grams of wheat after 24 months (table 1). By the end of the third year the untreated wheat averaged a little more than 100 live insects per 1,000 grams of wheat.

Malathion was the most effective field treatment in the series. The malathion-treated wheat remained insect-free for a period of 2 years and contained only an average of 0.4 insect per 1,000 grams of wheat at the end of 3 years of storage.

Perma-Guard was second in performance. In 10 of the 13 sampling periods no insects were found in the Perma-Guard-treated wheat. Samples were insect-free in two of the four samp-

TABLE 1.—*Average numbers of insects found in wheat samples*[1] *taken over a 3-year period from treated and untreated binned wheat at McPherson, Kans.*

Months after treatment	Perma-Guard	Kenite 2-I	SG-68	Cab-O-Sil	Malathion	Untreated check
	Number	*Number*	*Number*	*Number*	*Number*	*Number*
1....	0	0	0	0	0	<0.1
3....	0	0	0	0	0	0
6....	0	0	0	0	0	0
9....	0	0	0	0	0	0
12....	0	0	0	0	0	.1
15....	0	0	0	0	0	.3
18....	0	0	0	0	0	0
21....	0	0	0	0	0	.7
24....	2.6	2.8	2.8	77.0	0	39.9
27....	.4	28.7	68.5	160.3	<0.1	45.7
30....	0	<0.1	30.7	15.5	0	10.8
33....	0	.8	3.8	6.1	0	60.5
36....	1.8	43.9	112.1	125.0	.4	100.1

[1]Each sample weighed 1,000 grains.

lings the third year. There was an average of 1.8 insects per 1,000 grams of wheat at final sampling, 36 months after treatment; only two species constituted the infestation—the lesser grain borer and the longheaded flour beetle.

Kenite 2-I rated third with an average of 43.9 insects per 1,000 grams of wheat at the 36-month sampling.

The silica aerogels, Cab-O-Sil and SG-68, treatments did not develop insects early in the test, but neither did the check. At the end of the test period, both treatments harbored more insects than the untreated check wheat.

Comparative abundance of insect species

The relative abundance of different species of insects found in the treated and untreated wheat are recorded in table 2. This table covers the period of the test in which most of the insects were found, 24 to 36 months. There were a number of species that were not originally introduced; they were native and developed wild populations.

The lesser grain borer was the most predominent species found in all of the inert dust treatments, but this species was noticeably absent in four of the five malathion bins and there were few in the checks.

The longheaded flour beetle was found in some of the bins of all of the inert dust treatments, but it was not found in wheat treated with malathion, and few beetles were found in the untreated check wheat.

The flat grain beetle appeared in the untreated check bins and some of the bins of each treatment series except the Perma-Guard series.

The red flour beetles were most abundant in the silica-aerogel-treated wheat, and they were found in all treatment series; fewest were recovered from the malathion treatments. They were found in only one of the five untreated check bins.

Dermestids were present in great abundance in the untreated wheat but were apparently controlled by all the treatments. No dermestids were recovered from the Perma-Guard-treated wheat.

Sawtoothed grain beetle populations were not as great, even in the untreated wheat, as might be expected; none were found in the Perma-Guard-, Kenite 2-I-, and malathion-treated wheats.

The rice weevil was noticeably absent in treated and untreated wheat alike. In all probability the low-moisture content of the wheat was a factor that was not conducive to its population development.

There was a striking increase in the total number of insects found in the wheat samples taken from each 5-bin treatment series 24 to 36 months after treatment. Malathion-treated wheat had the fewest total number of insects with 16, Perma-Guard followed with 196, Kenite 2-I with 3052, SG-68 with 8708, and Cab-O-Sil with 15,354, in that order. The untreated wheat samples contained 10,274 insects.

Insect location

The locations of the 24 to 36-month insect populations within the 3,250-bushel bins of treated and untreated wheat are shown in table 3.

Nearly all the insects found in the Perma-Guard-treated wheat were located on the grain surface, and fewer insects were found within the grain mass than in any other treatment.

Insects were more widely spread in the top 5

TABLE 2.—*Comparative abundance and number of insects found in 1,000-gram wheat samples taken from five 3,250-bushel bins of each treatment series, 24 to 36 months after treatment, McPherson, Kans.*

Treatment and months after treatment	Total insects	Lesser grain borer	Longheaded flour beetle	Flat grain beetle	Red flour beetle	Dermestids	Sawtoothed grain beetle	Rice weevil
	Number	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Perma-Guard:								
24	110	65.5	0	0	34.5	0	0	0
27	14	42.9	42.9	0	14.2	0	0	0
30	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
36	72	25.0	75.0	0	0	0	0	0
Kenite 2-I:								
24	114	68.4	0	19.3	12.3	0	0	0
27	1,148	65.5	15.7	5.4	13.4	0	0	0
30	2	0	0	0	0	100.0	0	0
33	32	62.5	0	37.5	0	0	0	0
36	1,756	61.3	33.8	.2	4.7	0	0	0
SG-68:								
24	112	100.0	0	0	0	0	0	0
27	2,738	57.0	18.0	2.4	22.6	0	0	0
30	1,226	13.2	17.1	3.8	65.9	0	0	0
33	150	73.3	26.7	0	0	0	0	0
36	4,482	48.4	24.0	25.0	2.6	< .1	< .1	0
Cab-O-Sil:								
24	3,080	96.0	0	1.1	2.9	0	0	0
27	6,412	74.3	14.0	.4	11.2	.1	0	0
30	618	4.5	1.0	3.2	91.3	0	0	0
33	244	96.7	2.5	.8	0	0	0	0
36	5,000	83.1	13.8	1.1	1.6	0	.1	.4
Malathion (standard):								
24	0	0	0	0	0	0	0	0
27	2	0	0	100.0	0	0	0	0
30	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0
36	14	57.1	0	14.3	14.3	14.3	0	0
Check (untreated):								
24	1,594	2.0	0	9.5	0	88.2	.2	0
27	1,826	.2	0	12.4	0	87.2	.2	0
30	430	0	0	.9	0	97.7	1.4	0
33	2,420	0	0	0	0	100.0	0	0
36	4,004	27.1	.2	22.5	4.3	45.8	0	0

feet of wheat in the Kenite 2-I series, and most were in the center.

Thirty-six months after treatment (in October) insects were found in four of the five malathion-treated bins of wheat with the insects located on the surface and in the top 5 feet of grain.

Insect populations in the silica-aerogel bins were highest in the samples from the surface and top 5 feet. There were fewer insects at the bottom of the grain mass.

Insects were found throughout the grain mass of untreated check wheat, but the greatest numbers were recovered from the surface areas.

In the 5-sampling periods during the last year of the test, 25 bin inspections were made in each treatment series. Of the 25 inspections in each treatment, 4 Perma-Guard, 8 Kenite 2-I, 15 SG-68, 15 Cab-O-Sil, 5 malathion, and all 25 untreated-check inspections showed living insect populations (see "Bins infested," table 3).

Repellency tests

All of the inert dusts tested displayed considerable repellency (table 4). The diatomaceous

TABLE 3.—*Location of insects found in treated and untreated 3,250-bushel bins of wheat and the number of bins infested 24 to 36 months after treatment, McPherson, Kans.*

Treatment and months after treatment	Surface	Center top 5 ft.	Center middle 5 ft.	Center bottom 5 ft.	North 5 ft.	East 5 ft.	South 5 ft.	West 5 ft.	Bins infested
Perma-Guard:	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Number*
24	98.2	1.8	0	0	0	0	0	0	1
27	100.0	0	0	0	0	0	0	0	1
30	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0
36	100.0	0	0	0	0	0	0	0	2
Kenite 2-I:									
24	96.5	3.5	0	0	0	0	0	0	1
27	25.6	17.3	0	.2	0	0	0	57.0	2
30	0	100.0	0	0	0	0	0	0	1
33	0	93.8	6.3	0	0	0	0	0	1
36	38.6	26.4	.1	0	.1	34.6	.1	0	3
SG-68:									
24	64.3	33.9	0	0	0	0	0	1.8	2
27	84.8	15.1	.2	0	0	0	0	0	3
30	76.0	23.8	0	.2	0	0	0	0	3
33	42.7	50.7	0	0	0	0	0	4.0	3
36	85.0	14.0	0	< .1	.5	< .1	< .1	.3	4
Cab-O-Sil:									
24	88.7	11.1	< .1	0	.1	0	0	0	2
27	73.8	25.9	.1	.2	0	0	0	< .1	4
30	97.1	2.9	0	0	0	0	0	0	2
33	78.7	20.5	.8	0	0	0	0	0	3
36	79.3	20.1	< .1	.1	.3	0	< .1	< .1	4
Malathion:									
24	0	0	0	0	0	0	0	0	0
27	100.0	0	0	0	0	0	0	0	1
30	0	0	0	0	0	0	0	0	0
33	0	0	0	0	0	0	0	0	0
36	42.9	28.6	0	0	14.3	14.3	0	0	4
Check (untreated)									
24	54.2	12.4	.5	.3	13.3	7.3	4.0	8.0	5
27	86.0	2.4	.1	.1	5.8	1.5	2.7	1.3	5
30	63.3	3.3	0	0	7.9	14.0	4.7	7.0	5
33	54.0	6.6	.3	.2	6.4	8.4	16.5	7.9	5
36	46.8	16.2	.4	.4	3.3	9.6	10.7	12.5	5

earths, Perma-Guard and Kenite 2-I, were more repellent than the silica aerogels and displayed less variation during the test period in percent repellency. Malathion-treated wheat initially showed slight repellency, then gradually became less repellent to the test insects as time prog-

Bioassay tests

Bioassay results (table 5, pages 12, 13) show:

1. Both of the diatomaceous earth treatments resulted in nearly 100 percent mortality of the adult rice weevils throughout the test. After 3 years, both Perma-Guard and Kenite 2-I provided no reduction in effectiveness against the test insects under controlled conditions.

2. The malathion treatment resulted in ally high (nearly 100 percent) mortality of rice weevil adults for a period of 2 years. :tality counts of test insects were slightly less third year.

TABLE 4.—*Repellency of treated wheat toward weevils over 36-months after treatment*

Number of months	Repellency of Treatments				
	Perma-Guard	Kenite	SG-68	Cab-O-Sil	Malathion
	Percent	*Percent*	*Percent*	*Percent*	*Percent*
1	85.6	90.0	62.3	71.1	8.0
3	87.8	91.0	75.5	69.8	29.4
6	81.1	78.4	59.8	57.5	12.9
9	93.C	94.2	90.4	82.2	2.7
12	79.0	88.5	64.2	58.7	–15.6
15	86.1	91.0	64.5	32.1	6.3
18	80.1	81.8	63.4	62.9	15.0
21	80.2	91.3	73.0	74.6	–4.2
24	92.4	90.6	67.7	74.6	–14.4
27	85.8	82.3	41.1	33.7	–0.6
30	82.7	86.8	57.4	62.4	7.8
33	90.8	76.8	38.5	44.3	–5.4
36	92.8	90.7	69.8	68.1	–19.0

3. The silica aerogels, Cab-O-Sil and SG-68, closely followed the malathion pattern in causing mortality of the adult rice weevils throughout the test. Mortality was lowest the third year.

4. Progeny mortality of the rice weevils was highest in the diatomaceous earth-treated wheat —nearly 100 percent throughout the test. Both of the diatomaceous earth-treated wheats, had shown 100-percent mortality in counts of the rice weevil progeny the third year after grain treatment.

5. The malathion-treated wheat gave high rice weevil progeny mortality for 2 years, but mortality was reduced to about 82 percent the third year.

6. The diatomaceous earth-treated wheat produced higher adult lesser grain borer mortalities throughout the test than did either malathion or the silica aerogels.

7. The lesser grain borer mortalities, both adult and progeny, were considerably less and the counts more erratic in all treatments than were those of the rice weevil.

8. The malathion-treated wheat consistently produced fewer lesser grain borer progeny than the other treatments.

Malathion residue analysis

The results of the analysis, expressed in parts per million, table 6, show that malathion residues persisted at relatively high levels throughout the test period. One month after treatment the average recovered malathion residue from the wheat was 7 p/m; after 12 months, 5.5 p/m; 24 months, 4.7 p/m; and 36 months, 4.1 p/m.

Commercial grade

Inert dust treatments immediately reduced the wheat grades from U.S. No. 1 to U.S. No. 3 (table 7). Lowered test weight (TW) was the predominant downgrading factor of the dust-treated wheats. Malathion-treated and untreated (check) wheat were downgraded chiefly on the basis of foreign material (FM) and total defects (TDF).

Wheat test weight

Test weights reported in table 8 represent the ranges and averages of samples from five bins of each treatment.

The diatomaceous earth treatments reduced the test weight of wheat by an average of 3.2 pounds per bushel.

The test weight of the silica-aerogel-treated wheat averaged 3.3 pounds per bushel less after treatment.

The test weight of the malathion-treated wheat remained unchanged by the treatment.

Reduction in test weight of wheat treated with the four inert dust materials resulted because the dust coating on the kernels altered the nestling properties of the wheat, allowing less wheat per given volume.

TABLE 6.—*Residue on wheat from samplings of 5 malathion-treated bins, McPherson, Kans.*

Months	Malathion residue recovered from bin number —						
	705	711	772	780	170	Average	Untreated check
	Parts per million						
1.......	6.9	7.5	6.1	5.9	8.6	7.0	<0.5
3.......	7.0	6.9	7.0	6.0	4.9	6.3	—
6.......	9.4	8.0	9.2	7.5	7.1	8.2	.7
9.......	8.3	7.3	7.7	7.1	4.7	7.0	< .5
12.......	4.7	6.0	5.6	5.6	5.6	5.5	< .5
15.......	6.7	7.2	5.1	5.3	6.2	6.1	.2
18.......	5.5	6.1	6.1	5.8	5.1	5.7	.5
21.......	4.8	5.4	5.4	4.5	3.9	4.8	< .5
24.......	4.7	4.9	5.2	4.2	4.4	4.7	< .5
27.......	3.9	4.8	4.6	4.2	3.5	4.2	< .2
30.......	3.7	4.3	3.9	3.2	3.3	3.7	< .3
33.......	3.6	4.1	4.4	3.4	2.9	3.7	< .2
36.......	3.7	4.3	4.5	4.2	3.8	4.1	< .2

TABLE 5.—*Laboratory bioassay-mortality of rice weevils and*

Treatment and age of samples	Rice weevils: Adult mortality	Rice weevils: Progeny	Rice weevils: Progeny mortality	Lesser grain borers: Adult mortality	Lesser grain borers: Progeny	Lesser grain borers: Progeny mortality
Perma-Guard:	*Percent*	*Number*[1]	*Percent*	*Percent*	*Number*[1]	*Percent*
1 month	100.0	0	—	92.8	2	100.0
3 months	100.0	7	100.0	97.4	164	58.5
6 months	100.0	16	100.0	93.7	14	100.0
9 months	100.0	17	100.0	87.0	83	67.5
12 months	100.0	104	100.0	80.0	48	79.2
15 months	100.0	105	99.1	93.7	7	57.1
18 months	100.0	68	100.0	87.2	40	52.5
21 months	100.0	52	98.1	91.6	53	39.6
24 months	100.0	66	100.0	92.8	46	52.2
27 months	100.0	75	100.0	86.3	70	51.4
30 months	100.0	90	100.0	96.8	26	61.5
33 months	100.0	17	100.0	96.8	38	36.8
36 months	100.0	50	100.0	91.8	84	20.2
Kenite 2-I:						
1 month	100.0	0	—	93.4	12	100.0
3 months	100.0	5	100.0	97.1	66	60.6
6 months	100.0	4	100.0	90.4	14	92.9
9 months	91.6	8	100.0	100.0	115	80.0
12 months	100.0	155	100.0	80.1	54	70.4
15 months	100.0	112	100.0	93.2	11	100.0
18 months	100.0	88	100.0	92.2	28	67.9
21 months	99.6	57	100.0	90.8	35	62.9
24 months	100.0	79	100.0	87.8	41	58.5
27 months	100.0	100	100.0	77.3	168	53.6
30 months	100.0	125	100.0	93.3	54	61.1
33 months	100.0	18	100.0	92.2	42	38.1
36 months	100.0	69	100.0	80.1	151	37.8
SG-68:						
1 month	98.3	215	80.0	76.1	9	0
3 months	100.0	10	100.0	83.1	39	64.1
6 months	98.8	48	33.3	96.9	9	88.9
9 months	100.0	18	100.0	87.7	87	35.6
12 months	100.0	208	84.1	80.7	20	50.0
15 months	81.6	1459	5.5	86.0	9	22.2
18 months	100.0	383	47.0	68.8	35	20.0
21 months	100.0	405	17.3	69.9	113	22.1
24 months	94.3	765	10.7	76.3	37	10.8
27 months	83.2	1227	3.0	44.4	288	11.5
30 months	84.2	1133	6.5	84.3	122	14.8
33 months	99.3	61	65.6	73.8	74	10.8
36 months	92.2	512	15.6	63.1	90	12.2

Moisture content of wheat

The wheat in all the bins was of uniformly low moisture content before treatment (table 9).

There was a noticeable, 0.3 to 0.4 percent average, reduction in the recorded moisture of the wheat immediately after treatment with inert dusts; as previously indicated, this was not an actual loss of moisture.

Milling and baking tests

C. C. Fifield's studies (*9*) show that:

A. The reduction in test weight of the wheat

lesser grain borers in bin-treated wheat at 3-month intervals

Treatment and age of samples	Rice weevils			Lesser grain borers		
	Adult mortality	Progeny	Progeny mortality	Adult mortality	Progeny	Progeny mortality
Cab-O-Sil:	*Percent*	*Number*[1]	*Percent*	*Percent*	*Number*[1]	*Percent*
1 month	99.2	35	100.0	85.8	2	50.0
3 months	100.0	327	100.0	82.0	91	56.0
6 months	100.0	94	50.0	96.5	12	83.3
9 months	100.0	22	90.9	92.5	78	34.6
12 months	87.1	1009	16.2	36.0	72	15.3
15 months	80.8	1256	6.0	92.9	32	31.3
18 months	82.4	575	20.9	64.1	131	9.2
21 months	100.0	191	40.3	88.4	86	22.1
24 months	98.1	293	45.7	84.2	82	17.1
27 months	91.3	653	14.4	57.6	505	8.3
30 months	80.9	894	10.5	92.2	117	24.8
33 months	99.6	43	58.1	87.7	116	11.2
36 months	90.2	377	26.3	69.3	126	13.5
Malathion (standard):						
1 month	100.0	2	100.0	93.0	4	100.0
3 months	100.0	22	100.0	97.6	7	100.0
6 months	100.0	30	100.0	100.0	10	100.0
9 months	100.0	71	100.0	87.3	10	80.0
12 months	100.0	696	91.5	63.7	26	50.0
15 months	100.0	556	99.5	65.5	6	33.3
18 months	100.0	232	99.6	42.9	10	70.0
21 months	100.0	317	97.2	47.1	16	56.3
24 months	99.6	449	99.3	57.5	12	41.7
27 months	97.7	815	92.9	14.4	22	31.8
30 months	98.4	943	82.2	47.4	16	25.0
33 months	99.6	247	79.0	30.0	16	18.8
36 months	92.8	890	73.4	17.8	18	11.1
Check (untreated):						
1 month	1.6	3341	1.3	27.5	156	5.1
3 months	8.7	1296	8.3	9.2	415	31.3
6 months	6.5	2259	5.7	28.6	229	24.0
9 months	4.1	4448	3.4	13.0	3643	2.6
12 months	.8	6102	.5	20.5	126	2.4
15 months	1.6	6388	.3	32.8	427	3.8
18 months	2.8	4707	.8	5.5	1733	3.3
21 months	2.0	2686	.7	6.7	3880	1.8
24 months	1.5	6259	.5	6.0	1928	2.0
27 months	1.5	8675	.2	2.9	1944	1.2
30 months	2.3	5180	.6	12.9	1598	4.2
33 months	7.4	3551	.8	13.9	616	.7
36 months	3.2	5252	.4	6.6	1662	1.7

[1] Total number found in 5 jars (1 from each bin treated).

treated with either type of inert dust did not affect the flour yield.

B. Dusted wheats did not change in numerical grade during 36 months of storage.

C. Initial insecticide treatments of the samples had no material effect on the chemical or physical properties of the doughs or bread-baking properties. Cab-O-Sil-treated and check wheat showed lower initial fat acidity values than the other treated wheats.

D. Fat acidity values for all samples increased appreciably during storage with the

TABLE 7.—*Commercial grades*[1] *and primary factors*[2] *responsible*

Treatment and bin number	Before treatment		Following treatment		1 year after treatment		2 years after treatment		3 years after treatment	
	Grade	Factor	Grade	Factor	Grade	Factor	Grade	Factor	Grade	Factor
Perma-Guard:										
162	3HW	SB	3HW	TW	3HW	TW	3YHW	TW	3YHW	TW
173	2HW	TW	4HW	TW	3HW	TW,TDF	3YHW	TW	3HW	TW,TDF
189	1YHW	—	3YHW	TW	3YHW	TW	3YHW	TW	3HW	TW
706	1YHW	—	3YHW	TW	3YHW	TW,TDF	3YHW	TW,TDF	3HW	TW
776	3YHW	SB	3YHW	TW	4YHW	TDF	3YHW	TW,TDF	3HW	TW,TDF
Kenite 2-I:										
171	2YHW	FM	3HW	TW	3HW	TW	3HW	TW	3YHW	TW
703	3HW	FM	3HW	TW,FM	4HW	TDF	3HW	TW,TDF	4HW	TDF
709	2HW	TW	3HW	TW	3HW	TW,TDF	3YHW	TW,TDF	3YHW	TW
775	2YHW	TW	3YHW	TW	3YHW	TW	3HW	TW,TDF	3HW	TW
783	1HW	—	3HW	TW	3HW	TW,TDF	3YHW	TW	4HW	TDF
SG-68:										
701	2HW	TW	3HW	TW	3HW	TDF	3HW	TW,TDF	3HW	TW
704	2HW	FM	3HW	TW	3HW	TW,TDF	3HW	TW,TDF	3HW	TW,SB,TDF
710	2YHW	TW	3YHW	TW	3YHW	TW,TDF	3HW	TW,TDF	3HW	TW,TDF
755	2HW	TW	3YHW	TW	3HW	TW,TDF	3HW	TW	3HW	TW,TDF
773	2HW	TW	3HW	TW	3HW	TW	3HW	TW	3HW	TW,TDF
Cab-O-Sil:										
172	2YHW	TW	3HW	TW	3HW	TW	3YHW	TW	3YHW	TW,TDF
707	2YHW	TW	3YHW	TW	3YHW	TW,TDF	3HW	TW	3HW	TW,SB,TDF
712	3DHW	TW	5DHW	TW	5DHW	TW	5HW	TW	4DHW	TW
754	2HW	FM	3HW	TW	3HW	TW,TDF	3HW	TW,TDF	3HW	TW,TDF
784	3DHW	FM	3HW	TW,FM	3DHW	TW,FM	3HW	TW	3DHW	TW
Malathion (standard):										
170	2HW	FM	2HW	FM	2HW	TW,FM,TDF	2YHW	TW,SB,TDF	2YHW	TW,SB,TDF
705	1HW	—	1HW	—	3HW	TDF	2HW	TW,SB,TDF	3HW	TDF
711	2HW	TW,FM	2HW	FM	3HW	TDF	3YHW	TDF	3HW	TDF
772	[3]3HW	FM	1HW	—	3HW	TDF	[3]3HW	TDF	[3]3HW	TDF
780	1YHW	—	1YW	—	2YHW	TDF	2YHW	TW,TDF	2HW	TW,SB,TDF
Check (untreated):										
161	1HW	—	2HW	FM	4HW	TDF	3HW	SB,TDF	3YHW	SB,TDF
165	2HW	FM	2HW	FM	3HW	TDF	3HW	TDF	3HW	TDF
191	1HW	—	1HW	—	3HW	TDF	2HW	SB,TDF	2YHW	SB,TDF
751	1YHW	—	1YHW	—	2YHW	TDF	2HW	TDF	3HW	TDF
785	2HW	FM	1HW	—	3HW	TDF	3HW	TDF	3YHW	TDF

[1] D = Dark; Y = Yellow; HW = Hard Winter.
[2] SB = Shrunken and broken kernels; TW = test weight; TDF = total defects; and FM = foreign material.
[3] Would have graded "Sample" because of stones.

TABLE 8.—*Test weight of wheat treated with inert dusts and malathion, taken over 3-years from 3,250-bushel metal bins, McPherson, Kans.*

Treatment	Before treatment		After treatment							
			Initial		1 year		2 years		3 years	
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
	Pounds per bushel									
Perma-Guard	59.8	58.7-60.2	56.7	55.7-57.5	56.8	56.0-57.5	56.8	56.0-57.5	56.9	56.2-57.5
Kenite 2-I	59.8	59.2-60.8	56.5	56.1-57.0	56.6	56.2-57.0	56.6	56.1-57.4	56.5	56.0-57.0
SG-68	59.5	59.0-60.0	56.4	56.1-56.7	57.2	56.2-60.3	56.7	56.5-56.8	56.5	56.0-56.8
Cab-O-Sil	59.4	57.4-60.3	55.9	53.8-56.6	56.1	53.3-57.7	56.0	53.8-56.8	56.1	54.0-57.0
Malathion (standard)	60.2	59.3-60.5	60.2	60.0-60.5	60.1	59.5-60.6	59.7	58.8-60.3	59.9	59.0-60.8
Check (untreated)	60.3	60.0-60.6	60.4	60.0-60.7	60.2	60.0-60.6	60.0	59.7-60.5	59.7	59.0-60.6

TABLE 9.—*Percentage moisture content of wheat treated with inert dusts and malathion, taken over 3 years from 3,250-bushel metal bins, McPherson, Kans.*

Treatment	Before treatment		After treatment							
			Initial		1 year		2 years		3 years	
	Average	Range	Average	Range	Average	Range	Average	Range	Average	Range
Perma-Guard	10.9	10.7-11.2	10.5	10.3-10.7	10.7	10.4-11.0	10.8	10.0-11.6	10.9	9.7-11.9
Kenite 2-I	10.8	10.7-11.0	10.4	10.2-10.7	10.6	10.4-10.9	10.9	10.0-12.0	10.9	9.6-11.9
SG-68	10.8	10.7-11.0	10.4	10.3-10.5	10.6	10.4-10.7	10.9	10.1-12.1	10.8	9.1-12.4
Cab-O-Sil	10.8	10.2-11.4	10.5	10.2-10.8	10.5	10.3-10.9	10.8	10.1-11.8	10.8	9.8-12.1
Malathion (standard)	10.9	10.7-11.3	10.9	10.5-11.3	11.1	10.9-11.2	11.1	10.3-12.4	11.0	9.9-12.4
Check (untreated)	10.8	10.5-11.0	10.7	10.5-10.9	10.9	10.7-11.0	11.2	10.1-12.3	11.1	9.9-12.2

greatest increase occurring in the last 6 months.

E. Sedimentation values, wheat protein content, ash content, and diastatic activity of flour from treated wheats were unchanged as compared with those of the untreated wheat.

F. Dough-mixing time, measured by the mixograph, increased moderately for all treatments, including the checks, while mixing tolerance remained unchanged during storage.

G. Neither the inert dusts nor the malathion appeared to influence the bread-baking properties.

Grain removal

When the bottom door retaining panels of the bins were removed, the inert dust-treated wheats flowed freely from the 3,250-bushel bins. The angle of repose of the wheat, however, had been increased by the inert dust treatments and less wheat flowed freely from the bins. Therefore, the workmen needed to scoop more grain from the dust-treated wheat bins than from the malathion and untreated bins.

Most airborne dust was associated with the diatomaceous earth-treated wheat as it was removed from the bins and loaded via screw-type augers into trucks (fig. 3).

Dusty conditions appeared to become less with subsequent handling—as the wheat was loaded via augers into railway gondola cars and shipped, (fig. 4).

PN-3965

FIGURE 3.—Diatomaceous earth-treated wheat being loaded into truck via screw auger during bin unloading at the end of the experiment.

Silica-aerogel-treated wheats were noticeably less chalky in appearance than were the diatomaceous earth-treated wheats (figs. 5 and 6). Also, less dust was encountered when the grain was handled.

No grain spoilage was found on the bottom or walls of the metal bins containing treated wheat; there was spoiled wheat in some of the untreated bins.

COMMENTS AND CONCLUSIONS

Data on the effectiveness of the five wheat treatments for controlling the insects and preventing reinfestation indicated that malathion and Perma-Guard were outstanding treatments. In some respects, malathion appeared slightly better than Perma-Guard; however, both treat-

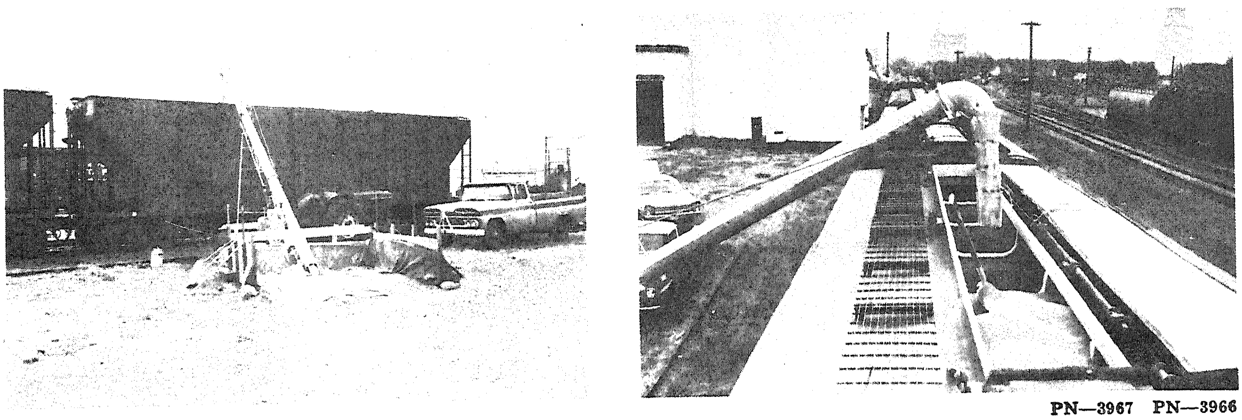

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FIGURE 4.—*(Left)* Diatomaceous earth-treated wheat being loaded via screw auger into railway gondola cars; *(right)* diatomaceous earth-treated wheat loaded in railway gondola cars showing little dust accumulations on the top of car.

ments prevented insect buildup in 3,250-bushel bulk grain storages for a period of 3 years under actual field conditions.

An influential factor that affected the results of this test was the moisture. The moisture content of the wheat was uniformly low in all bins. It was, however, sufficient to sustain insect growth and development. This was indicated both by bioassay tests and by the large insect populations found in the untreated wheat in the check bins. These conditions contributed to a slow rate of insect growth in the early stages of the test and benefited the ultimate performance of the treatments.

The exceptionally long period of effective insect control afforded by the malathion treatment for the most part, can be attributed to the low-moisture conditions. Apparently as indicated from residue analyses, the malathion remained at substantially effective levels in the bulk of the wheat 3 years after treatment.

The surface of the bin-stored grain varied in moisture content throughout the year. This was sometimes due to grain moisture migration or water in the form of rain or snow entering the bins.

Sometime during the 24th to 27th month (October-January), snow, blown by strong winds, briefly covered part of the surface of all test bins of wheat. This was reflected in increased surface grain moisture readings and contributed to an increased rate of insects. Normally, the surface

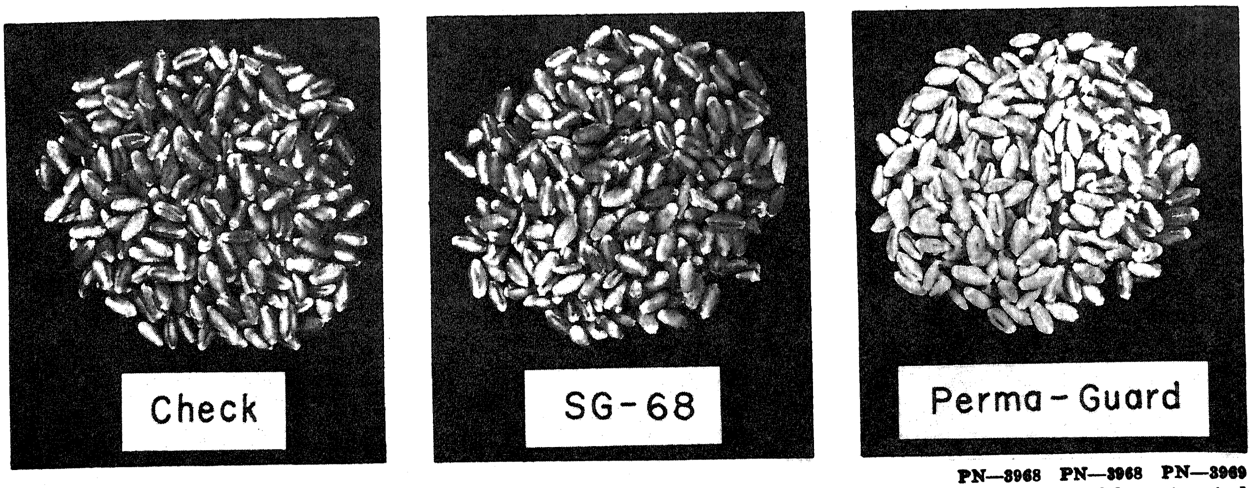

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FIGURE 5.—A comparison of the chalklike appearance of SG-68- and Perma-Guard-treated wheat with untreated check wheat.

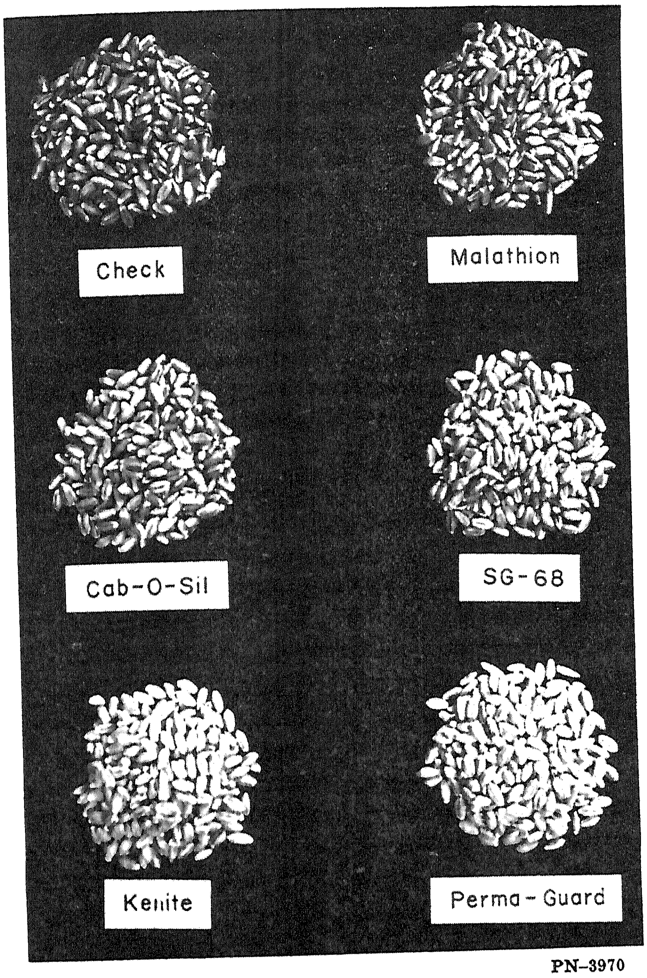

FIGURE 6.—Samples of treated and untreated wheat showing the effect of the treatments on grain appearance.

grain soon loses this moisture. The diatomaceous earth- and silica-aerogel-treated wheats, however, retained evidence of suface moisture in small (less than 5 bushels) areas of moldy wheat. Insects were associated with the moldy grain in some of the bins but not in others regardless of the type of treatment.

Although one would expect the two diatomaceous earth materials, because of their similarity, to be comparable in effectiveness, they were not. Both treatment series had light insect infestation at the 2-year sampling period in October. The lesser grain borer, for some unknown reason, increased in number from that time on in the Kenite 2-I-treated wheat but not not in the Perma-Guard-treated wheat.

When the wheat was sampled at the end of the test, both silica-aerogel-treated wheat and the untreated wheat contained about the same number of insects. The relatively poor performance of the silica-aerogel treatments could possibly be attributed to the low dosage levels. However, La Hue (*14*) reported that under semiambient conditions 60 pounds of Cab-O-Sil per 1,000 bushels of wheat (twice the dosage used in the tests reported here) in small 5-bushel bin tests resulted in good control of the lesser grain borer for 12 months.

Colburn C. Fifield 1970 (*9*), in processing the wheat samples from these tests, determined that the inert dust treatments did not affect the flour-yielding capacity, cause an increase in the ash content of the flour, nor adversely affect the initial bread baking properties of the flour. He did, however, report a slight decrease in crumb color and loaf volume, and a material reduction in crumb grain occurred as the length of storage time increased.

Problems associated with inert dust treatments of wheat are reduction of test weight, the chalky-white appearance of the diatomaceous earth-treated wheat, increased angle of grain repose, reduced flowability, and increased machinery stress, and the necessity of requesting (at additional cost) special processing during grading.

Whether the inert materials, such as those evaluated in these tests, can gain acceptance in the grain industry will depend not only upon their ability to control insects in grain, but also on whether the problems associated with their use can be overcome or outweighed by the incentive of maintaining chemical-free grain.

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